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| 13. ABSTRACT<br>A method is described for determining: (1) the minimum aperture size required to yield temperature rise data free from edge loss effects in measurements made at the center of a site during thermal irradiation of a semi-infinite solid; (2) the magnitude of edge losses due to restriction of the irradiated area to less than the "no loss" size, and its variation with respect to irradiance level and exposure time; and (3), where the thermal properties of the material are known, the energy absorption rate. The latter, on comparison with the measured incident energy also yields a measure of the absorptivity of the materials.<br><br>The relationship of edge losses to area size is shown to be a hyperbolic function conforming to the equation $Y = A + (B/X)$ where A and B are constants dependent upon the exposure time and irradiance level. The edge loss effect is shown to be directly dependent upon area irradiated and independent of the shape of the irradiated areas.<br><br>From the experimental data presented it is concluded that the method described is suitable for providing the information cited above with an accuracy limited only by that of the data collection technique. |  |   |                      |

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WARMINSTER, PA. 18974

Crew Systems Department

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Assessment of Temperature Rise Suppression  
by Edge Losses during Irradiation

Naval Air Systems Command  
AirTask ZR0000101/21  
Work Unit RB-6-01

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## SUMMARY

A method is described for determining: (1) the minimum aperture size required to yield temperature rise data free from edge loss effects in measurements made at the center of a site during thermal irradiation of a semi-infinite solid; (2) the magnitude of edge losses due to restriction of the irradiated area to less than the "no loss" size, and its variation with respect to irradiance level and exposure time; and (3), where the thermal properties of the material are known, the energy absorption rate. The latter, on comparison with the measured incident energy also yields a measure of the absorptivity of the materials.

The relationship of edge losses to area size is shown to be a hyperbolic function conforming to the equation  $Y = A + (B/X)$  where A and B are constants dependent upon the exposure time and irradiance level. The edge loss effect is shown to be directly dependent upon area irradiated and independent of the shape of the irradiated area.

From the experimental data presented, it is concluded that the method described is suitable for providing the information cited above with an accuracy limited only by that of the data collection technique.

On the other hand, sufficient data is available to show the variation in edge losses with exposure time for any fixed aperture ratio. As seen in Figure 5 (a, b, and c) for aperture ratios of 0.318, 0.516 and 0.643 (corresponding to mask areas 0.164, 0.266 and 0.331 respectively) the fall-off in  $Q'/Q$  is quite well-defined. At the highest irradiance and the largest aperture size used the edge losses appear to stabilize after 10 seconds irradiation. Perhaps all the loss vs time patterns would become asymptotic with time if heating were maintained long enough. In any event, it is evident that the exposure time as well as the aperture size exerts a large effect upon the temperature rise and that the total effect depends upon all three factors, viz., energy level, aperture size and exposure time.

### ACKNOWLEDGMENT

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## INTRODUCTION

During the experimental validation of an equation for the determination of temperature rise at depth in a two-layer system subjected to surface heating, a lower temperature rise per unit flux was observed on heating by irradiation through a square aperture, 0.500 inch\* on each side (0.250 in<sup>2</sup> in area), than through a circular aperture 0.776 inch in diameter (0.473 in<sup>2</sup> in area). This discrepancy might occur because the difference in total area irradiated resulted in greater heat loss at the edges of the smaller area, or the difference in aperture shape caused greater loss from the square area, or by both effects occurring simultaneously. Experimentation was undertaken to resolve the difficulty.

## MATERIALS AND METHOD

Masks were made from aluminum foil by cutting out 5 square and 5 circular apertures. The square apertures ranged in size from 0.164 in<sup>2</sup> to 0.331 in<sup>2</sup>. The circular apertures ranged from 0.161 to 0.336 in<sup>2</sup>. The masks were overlaid on a skin simulant of known thermal characteristics (1) and exposures were made with radiation from a tungsten-in-quartz lamp source (2). Temperature rise was measured at the center of each site at a depth of 0.5 mm beneath the surface of the simulant during exposure to each of three levels of energy. Twelve exposures were made at each energy level. The first and last were made with no mask and two exposures were made at each mask size starting with the smallest aperture and progressing to the next larger through the series of 5 sizes. To avoid over-heating the simulant, the exposure time was limited to 15 seconds at the highest energy level, 30 seconds at the intermediate, and 60 seconds at the lowest level. Temperature rise was measured continuously on a recording oscillograph (reading accuracy  $\pm 0.18^{\circ}\text{C}$ ) and the radiant flux was measured radiometrically (reading accuracy,  $\pm 0.006 \text{ cal/cm}^2 \text{ sec}$  before and after each series. The optical properties of the skin simulant produce a significant difference between incident and absorbed energy and it was more convenient to compute the surface heat absorbed than to find it by correcting for reflectance and transmittance. This calculation was made by computer from the relationship for temperature rise at depth in a semi-infinite solid (3):

$$\Delta T = \frac{Q}{k} \left[ \frac{2a\sqrt{t}}{\sqrt{\pi}} e^{-x^2/4a^2t} - x \left[ 1 - Q \left( \frac{x}{2a\sqrt{t}} \right) \right] \right]$$

where  $\Delta T$  = temperature rise ( $^{\circ}\text{C}$ )

\* Apparatus tooled in inches; equivalent metric units available from conversion factors: 1 inch = 2.54 cm; 1 inch<sup>2</sup> = 6.45 cm<sup>2</sup>.



$Q$  = surface flux ( $\text{cal}/\text{cm}^2\text{sec}$ )

$k$  = thermal conductivity ( $\text{cal}/\text{cm sec } ^\circ\text{C}$ )

$a$  = thermal diffusivity ( $\text{cm}^2/\text{sec}$ )

$t$  = time (sec)

$x$  = depth (mm)

The unmasked exposure aperture was circular,  $0.473 \text{ in}^2$  in area. Since there could be no assurance that this aperture itself was large enough to prevent edge losses, the "no loss" area was determined by extrapolation of the individual surface flux values at each mask size to the point of convergence with respect to aperture size.

Then, to determine the effect of each area restriction, the absorbed energy ( $Q'$ ) computed at several exposure times for each mask size was expressed as a ratio of the extrapolated values of energy absorbed at the "no loss" area size ( $Q$ ). This ratio ( $Q'/Q$ ) was plotted against the ratio of the area of the mask aperture ( $A'$ ) to the "no loss" area ( $A$ ) and a family of curves was generated for each energy level.

#### EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1 shows the graphical extrapolation of the absorbed energy ( $Q'$ ) as calculated from observed  $\Delta T$ s to the "no loss" aperture area for several exposure times at the three levels of energy incident. In each instance the "no loss" area was found to be  $0.515 \text{ in}^2$ . Similarly the absorbed energy was indicated as  $0.121 \text{ cal}/\text{cm}^2\text{sec}$  at the 0.19 incident energy level,  $0.256$  at the 0.42 level and  $0.431$  at the 0.70 level. (Thus, the absorptivity of the simulant for this energy range was about 64 to 61%, being higher at the lower irradiances where less visible radiation, and therefore less reflection by the simulant, occurs.) The equation of the curve was determined for the highest input using a least squares fit. It was found to be  $Y = A + (B/X)$ , a hyperbolic function, in which  $A = 0.461$  and  $B = -0.015$  at the 15-second exposure time,  $0.451$  and  $-0.010$  respectively at the 10-second level,  $0.439$  and  $-0.005$  at the 5-second and  $0.437$  and  $-0.002$  at the 2.5-second level. The mathematical extrapolation of these curves yields a mean value of  $0.4315 \pm 0.00125$  ( $\sigma = .000957$ ). The data at the other levels of energy are of the same nature. These findings indicate that the "no loss" area may be assayed in a similar manner for any series of apertures, given only the temperature-time history measured at a known depth in a material of known properties.

Table I shows the comparison of the  $Q'/Q$  ratios for each aperture size of both the square and the circular masks at the intermediate energy level. The same data are shown graphically correlated with the area

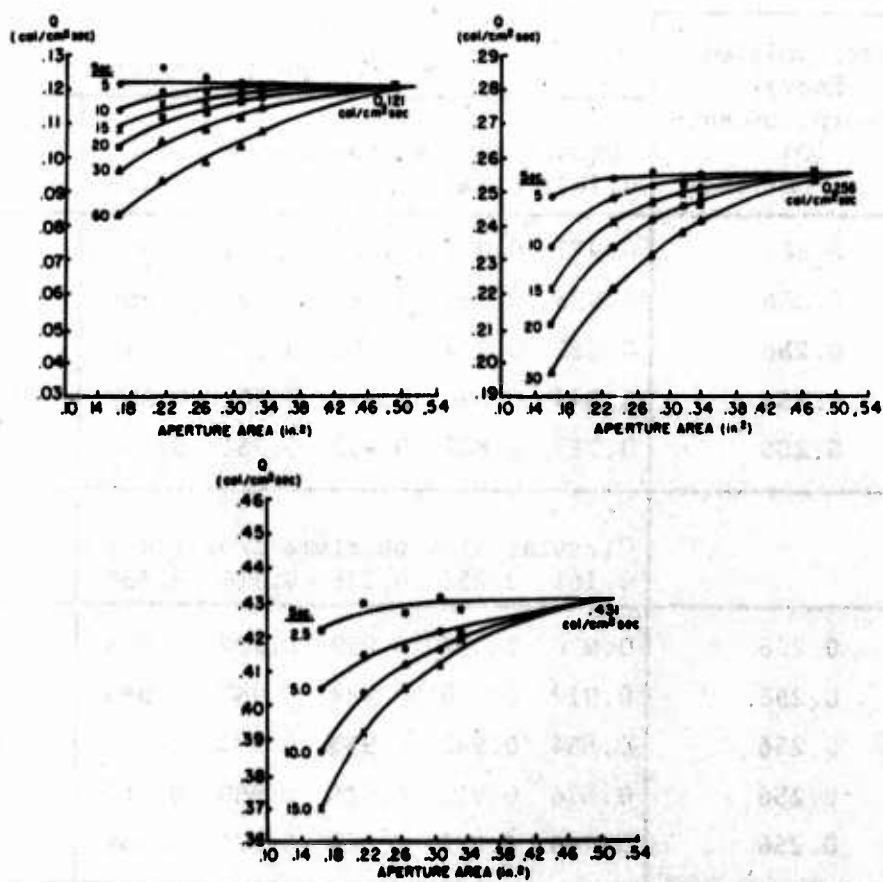


Figure 1. Determination of "no loss" area by extrapolation.

TABLE I

COMPARISON OF ENERGY ABSORPTION RATIOS FOR EXPOSURES WITH SQUARE AND CIRCULAR APERTURES (OBSERVED DATA)

| Exposure Time (Sec) | Extrapolated Energy Absorption Rate (Q) cal/cm <sup>2</sup> sec | Ratio of computed energy absorption (Q'/Q)     |       |       |       |       |                     |
|---------------------|---|--|-------|-------|-------|-------|---------------------|
|                     |   | Square mask aperture area (in <sup>2</sup> )   |       |       |       |       | (Circular) Unmasked |
|                     |   | 0.164  | 0.214 | 0.266 | 0.306 | 0.331 | 0.473               |
| 5                   | 0.256   | 0.977  | 0.994 | 1.015 | 1.012 | 1.002 | 1.015               |
| 10                  | 0.256   | 0.923  | 0.961 | 0.984 | 0.999 | 0.986 | 0.997               |
| 15                  | 0.256   | 0.882  | 0.924 | 0.965 | 0.979 | 0.982 | 1.001               |
| 20                  | 0.256   | 0.843  | 0.896 | 0.941 | 0.962 | 0.967 | 0.998               |
| 30                  | 0.256   | 0.787  | 0.849 | 0.902 | 0.931 | 0.945 | 1.000               |
|                     |   | Circular mask aperture area (in <sup>2</sup> ) |       |       |       |       |                     |
|                     |   | 0.161  | 0.233 | 0.278 | 0.316 | 0.336 |                     |
| 5                   | 0.256   | 0.970  | 1.007 | 0.999 | 0.984 | 0.998 | 0.997               |
| 10                  | 0.256   | 0.912  | 0.970 | 0.984 | 0.987 | 0.983 | 1.000               |
| 15                  | 0.256   | 0.864  | 0.942 | 0.963 | 0.973 | 0.971 | 1.000               |
| 20                  | 0.256   | 0.826  | 0.912 | 0.945 | 0.960 | 0.962 | 0.998               |
| 30                  | 0.256   | 0.768  | 0.872 | 0.910 | 0.928 | 0.939 | 0.989               |



ratio ( $A'/A$ ), Figure 2. The observed data correspond to area ratios of 0.318, 0.416, 0.516, 0.594, 0.643 and 0.918 (given as percent, 31.8, 41.6, etc.) The points at  $A'/A = 0.7, 0.8$  and  $0.9$  were inserted from the mathematical solution of the curve ( $Y = A+B/X$ ) for each exposure time to compensate for lack of experimental data in this area. It is readily seen that in no instance is the difference of the mean curve from the square and from the circular apertures greater than 1%, well within experimental limits (about 2.5%), indicating that the shape of the aperture is of no real consequence.

Table II presents the  $Q'/Q$  ratios for all energy levels at exposure times of 5, 10 and 15 seconds. These ratios, expressed in percent with their equivalent values as edge losses, are shown graphically in Figure 3 on the ordinates with their corresponding area ratios ( $A'/A$ ) on the abscissa. It is seen that the  $Q'/Q$  ratio (left ordinate) decreases, which means the edge losses (right ordinate) increase, with an increase in the energy level and with an increase in the exposure time. For instance, at a given area ratio and exposure time where  $A'/A = 55\%$  and exposure time = 10 seconds, the edge losses increase from 1.0% at 0.121 cal/cm<sup>2</sup>sec surface flux to 4.0% at 0.431 cal/cm<sup>2</sup>sec surface flux.

Where it is desired to find the edge losses applicable to a given aperture at a given surface flux value other than an observed point this relationship may be established as shown in Figure 4. Here edge losses at given aperture ratios and an exposure time of 10 seconds are plotted against the corresponding surface flux at the three energy levels used. The edge losses at any point within the observed range of energy may then be taken directly from this curve. No doubt, such curves may be extrapolated a reasonable distance beyond the observed range (dashed line) to provide estimates of edge losses outside the observed range. However, attempts to derive a single equation for such extrapolation were unsuccessful due to termination of energy input data at a point which proved to be critical to the form of the curve and the fact that the data yields a family of curves which become more linear as the area ratio decreases.

On the other hand, sufficient data is available to show the variation in edge losses with exposure time for any fixed aperture ratio. As seen in Figure 5 (a, b, and c) for aperture ratios of 0.318, 0.516 and 0.643 (corresponding to mask areas 0.164, 0.266 and 0.331 respectively) the fall-off in  $Q'/Q$  is quite well-defined. At the highest irradiance and the largest aperture size used the edge losses appear to stabilize after 10 seconds irradiation. Perhaps all the loss vs time patterns would become asymptotic with time if heating were maintained long enough. In any event, it is evident that the exposure time as well as the aperture size exerts a large effect upon the temperature rise and that the total effect depends upon all three factors, viz., energy level, aperture size and exposure time.



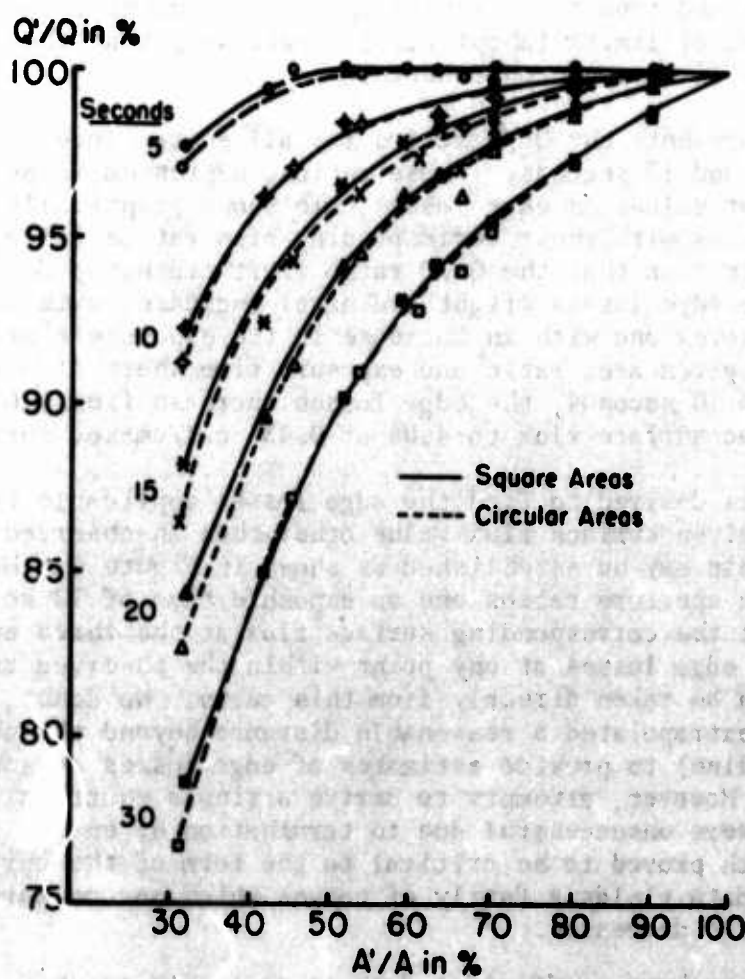


Figure 2. Comparison of energy and area ratios with square and circular apertures.

TABLE II

COMPARISON OF ENERGY ABSORPTION RATIOS AT EXPOSURE TIMES OF 5, 10  
AND 15 SECONDS AT THREE LEVELS OF IRRADIANCE (OBSERVED DATA)

| Exposure<br>Time<br>(sec) | Extrapolated<br>energy<br>Absorption rate<br>(Q)<br>cal/cm <sup>2</sup> sec | Ratio Q'/Q                                   |       |       |       |       |                   |
|---------------------------|---|--|-------|-------|-------|-------|-------------------|
|                           |   | Square mask aperture area (in <sup>2</sup> ) |       |       |       |       | Unmasked<br>0.473 |
|                           |   | 0.164  | 0.214 | 0.266 | 0.306 | 0.331 |                   |
| 5                         | 0.121   | 1.004  | 1.041 | 1.018 | 1.007 | 1.001 | 1.007             |
| 10                        | 0.121   | 0.945  | 0.985 | 0.982 | 0.994 | 0.997 | 1.003             |
| 15                        | 0.121   | 0.893  | 0.954 | 0.960 | 0.980 | 0.987 | 1.005             |
| 5                         | 0.256   | 0.977  | 0.994 | 1.015 | 1.012 | 1.002 | 1.015             |
| 10                        | 0.256   | 0.923  | 0.961 | 0.984 | 0.999 | 0.986 | 0.997             |
| 15                        | 0.256   | 0.882  | 0.924 | 0.965 | 0.979 | 0.982 | 1.001             |
| 5                         | 0.431   | 0.941  | 0.964 | 0.968 | 0.979 | 0.979 | 0.983             |
| 10                        | 0.431   | 0.899  | 0.938 | 0.957 | 0.966 | 0.976 | 0.992             |
| 15                        | 0.431   | 0.860  | 0.911 | 0.941 | 0.957 | 0.976 | 1.000             |

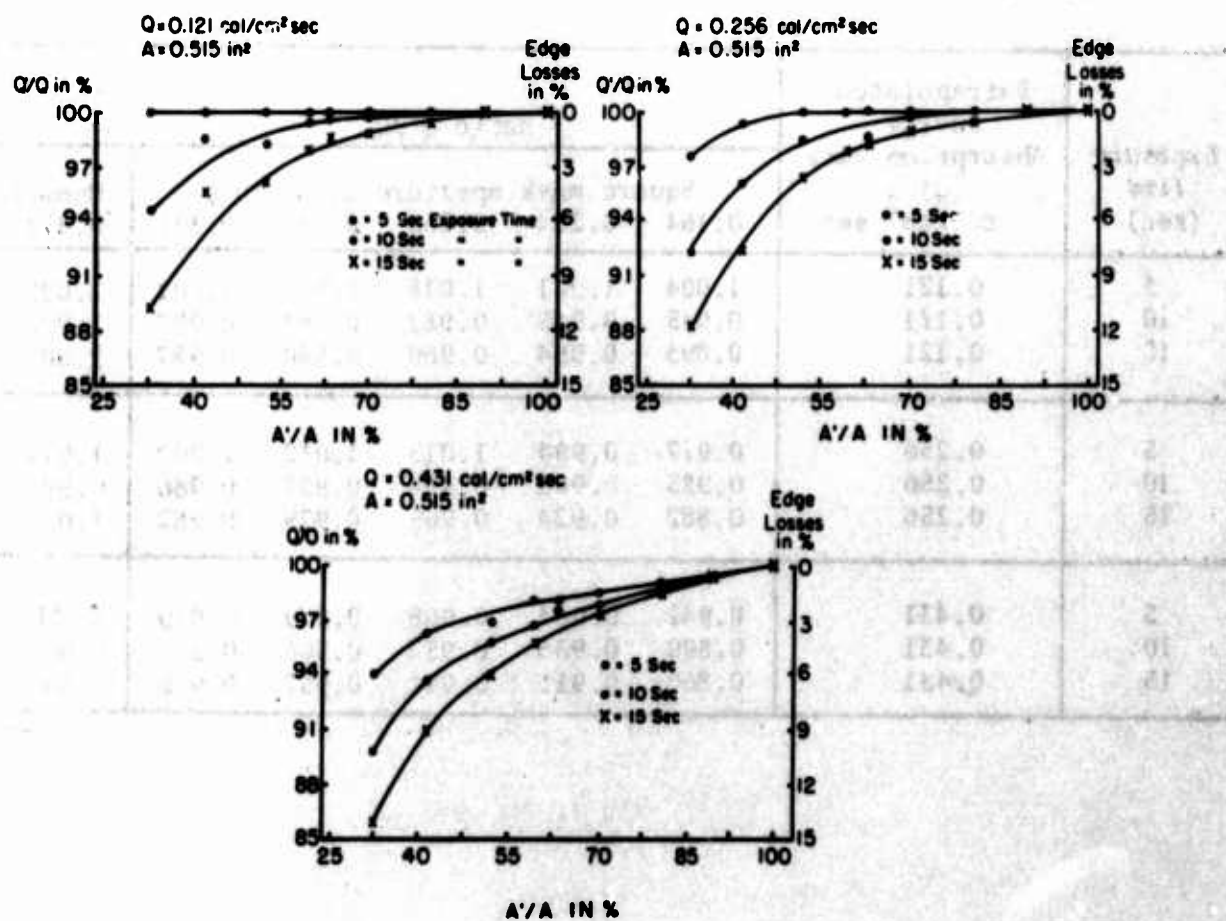


Figure 3. Correlation of energy and area ratios in three levels of irradiance.

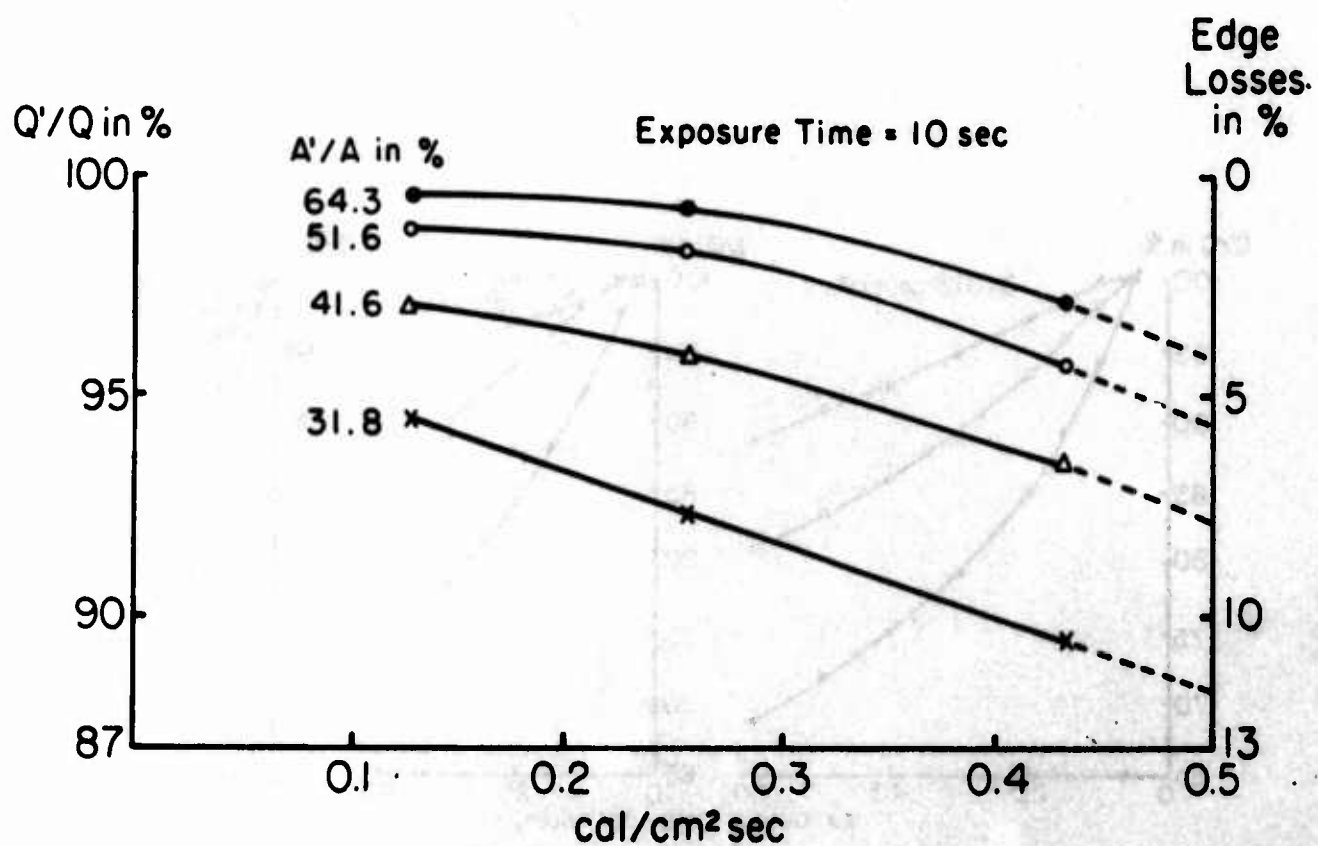


Figure 4. Variation in edge losses with energy absorption rate (from mean curves).



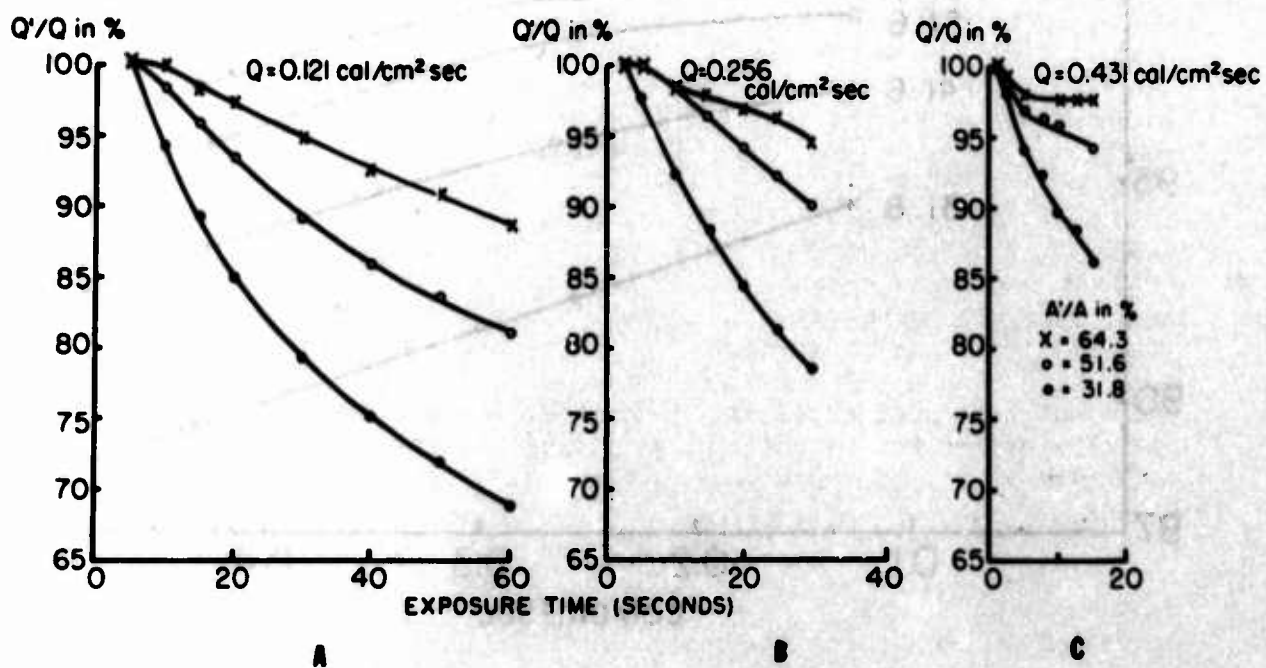


Figure 5. Variation in edge losses with exposure time (observed data).

Before concluding, it should be mentioned that since the measured temperature rise ( $\Delta T$ ) is directly proportional to the absorbed energy ( $Q$ ), as seen in the equation, if only a correction factor for  $\Delta T$  is required this may be obtained simply by substituting  $\Delta T$  for  $Q$  absorbed in Figure 1. If this is done then the point of convergence will indicate the "no loss" area and the  $\Delta T$  commensurate with this area. Indeed, where the properties of the material being heated are unknown there is no other choice, but where these properties are known the procedures described can provide far more information, as shown above.

#### SUMMARY AND CONCLUSION

A method is described for determining: (1) the minimum aperture size required to yield temperature rise data free from edge loss effects in measurements made at the center of a site during thermal irradiation of a semi-infinite solid; (2) the magnitude of edge losses due to restriction of the irradiated area to less than the "no loss" size, and its variation with respect to irradiance level and exposure time; and (3), where the thermal properties of the material are known, the energy absorption rate. The latter, on comparison with the measured incident energy also yields a measure of the absorptivity of the materials.

The relationship of edge losses to area size is shown to be a hyperbolic function conforming to the equation  $Y = A + (B/X)$  where  $A$  and  $B$  are constants dependent upon the exposure time and irradiance level. The edge loss effect is shown to be directly dependent upon area irradiated and independent of the shape of the irradiated area.

From the experimental data presented, it is concluded that the method described is suitable for providing the information cited above with an accuracy limited only by that of the data collection technique.

#### REFERENCES

1. Derksen, W.L., G.P. Delhery and T.I. Monahan. Thermal and optical properties of the NML skin simulant. Lab. Proj: 5046-3, 18 Jan 1960.
2. Stoll, A.M. Thermal protection of aviator's textiles. Aerospace Med. 33:846-850, July 1962.
3. Weaver, J.A. and A.M. Stoll. Mathematical model of skin exposed to thermal radiation. Aerospace Med. 40: 24-30, January 1969.